New LCA Thesis

Sustainable Development of Refrigerator Systems Using Replacement Environmentally Acceptable Refrigerants

Ph.D. thesis

Scientific assessments on climate change have led to the phase out of the dichlorodifluoromethane (CFC-12) refrigerant from the domestic refrigeration industry. One intriguing aspect is that anthropogenic chlorine in CFCs, which has ozone depletion and global warming implications when directly released to the environment, reacts with sliding surfaces forming laminated layers that reduce friction. With the increase in the rate of production of refrigerators, any deterioration of system performance due to the removal of this lubricating mechanism may adversely influence other environmental considerations.

Based on the above, the aim of this research is to address the sustainable development of domestic refrigeration systems using the replacement refrigerant tetrafluoroethane (HFC-134a). The work focuses on the emissions that may arise if the electrical consumption of the product deteriorates or its durability is curtailed. Tribological characteristics on compressor components influence both of these product attributes and therefore a thorough system analysis was carried out. An in-house built experimental test rig, which monitored slight variations in the electrical power drawn by a reciprocating hermetic compressor, was used under different experimental conditions. Furthermore, a detailed life cycle assessment on a domestic refrigerator was performed to help quantify the ensuing environmental burdens. In this way, a relation between tribological characteristics, power consumption and environmental impact was studied.

Primarily, the work focused on the refrigerant itself. Despite the increase in specific volume of HFC-134a compared to CFC-12, which results in a reduction of approximately 20% (by weight) in refrigerant per refrigerator, the environmental impact resulting from the synthesis of HFC-134a was found to increase by about 50% per domestic appliance. Secondly, the use of HFC-134a requires a change in compressor lubricant to ensure adequate miscibility with the refrigerant. This miscibility is essential in refrigeration applications and therefore the mineral oil used with CFCs is replaced with synthetic lubricants. The production of these synthetic lubricants, which require extreme pressure and anti-wear additives, constitute a lesser environmental impact than that of mineral oils. Although the additives themselves have a significant impact due to the use of zinc, sulphur, etc., synthetic oils generally provide greater flexibility for more efficient systems. For this reason a variety of oils, characterised by viscosity, were tested.

Experimental results have shown that the CFC substitute will increase friction and wear characteristics on the aluminium alloy connecting rod and the steel gudgeon pin. Low viscosity synthetic lubricants were tested but wear characteristics on both the connecting rod and the pin were significantly increased. With identical viscosities the CFC/mineral oil combination resulted in enhanced tribological properties, when compared to the HFC/synthetic oil combination, over the technical lifetime of the hermetic compressor. Throughout this study this lifetime was assumed to be 15 years with the compressor assumed to operate for 20% of this time. Continuous operation versus interrupted operation was also tested and the operating performance of the compressor was found to improve with the former for both the CFC and HFC combinations. The main reason for this was that the bulk oil temperature in the compressor was maintained.

For the interrupted tests, as experienced in *real-life*, the above tribological characteristics led to a maximum increase of approximately 54% in the electrical energy consumed throughout the technical lifetime of the compressor. The *energy-related* global warming implications, which scientific assessments of refrigerant compounds have failed to address, are set to rise with HFC-134a. The thesis considers a UK scenario, where greenhouse gases from the domestic refrigeration alone will increase to between 4.2 to 4.8 million tonnes of carbon dioxide equivalent by 2010, despite the change in refrigerant. These projected emissions are *energy-related* effects since, for the product considered here, the direct emissions are insignificant. Findings presented in this research, which assume that 12 million refrigerators are manufactured annually until 2010, account to approximately 20% of these UK projected emissions but these are unlikely to have been accounted for. This will undoubtedly prove a significant setback for governments aiming to reduce global warming implications from the domestic sector as a result of the Kyoto Protocol.

The systems-based approach applied throughout this research work identified no *indirect* benefits by switching to non-chlorinated refrigerants and this after only addressing tribological characteristics. It is important to mention that other considerations influenced by a change in lubricant, such as heat transfer characteristics at the heat exchangers, have not been addressed but may also influence compressor operation. The use of HFC-134a lessens compressor performance and this alone does not make the refrigerant or the refrigerator operating with this compound environmentally acceptable. What makes it worse is that if direct emissions of HFC-134a are further restrained then, for the refrigerator at least (for reasons of negligible direct effects), restraining CFC-12 rather than banning it would have resulted in a greater environmental benefit. This highlights the complexities that govern the environmental criterion on products indicating the unintended consequences that arise. For the case discussed here, focusing on the ozone depletion potential (ODP) or global warming potential (GWP) of a refrigerant compound as a *command and control* indicator is ineffectual. Indicators limit the number of available alternatives, which are a prerequisite to the concept of sustainability.

This thesis argues that for sustainable development of this product to be ensured then a change in refrigerant alone will not suffice. Such a change is in itself oxymoronic due to the high initial investment required for the development of a compound, which makes it impossible to be ignored without serious opposition and a consequent detriment to the environment. *Grace periods* sought by developing countries to be able to comply with new regulations, with the subsequent black market economies, will be inevitable as is still the case with the phase out of CFCs. Despite the financial constraints the domestic refrigeration industry faces, new design considerations, primarily aimed at servicing and extending the life of the hermetic compressor itself, are required and these have been considered throughout the latter part of this thesis. This work helps stimulate new ideas needed to address environmental issues influenced by traditional engineering disciplines. For this reason additional future research work, which will help characterise environmental implications further, have been outlined.

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